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Ethics of
Subglacial Lake Exploration
in Antarctica

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ABSTRACT

Current research shows tremendous promise for the exploration of subglacial lakes in Antarctica. Three projects to penetrate subglacial lakes are underway. The Russians are close to penetration of Lake Vostok, the British have plans to drill into Lake Ellsworth, and the U.S.A. WISSARD project plans to sample the Whillans Ice Stream in West Antarctica. The proposed explorations differ in technique and origin, however they all hope to test and analyze a subglacial aquatic environment using physical probes. This paper examines the history of the drilling attempts and discusses the technical aspects of the projects, including the types of drills, fluids used, and issues encountered. It also highlights the potential environmental risks posed by intrusion into the lakes and the ethical issues raised. It would appear that there are justifications for both sides of the debate on whether or not the drilling should proceed. The issues of legal position are also an important note in such a global and cross-cultural territory. As this kind of exploration has never been attempted before and is a prime example of human testing in extreme conditions, the space analogues are also acknowledged. Some conclusions are drawn as to the risk factors imposed by the exploration, and the potential benefits that could result from the data gained from within the lakes.

INTRODUCTION

It is proposed that the exploration of subglacial lakes could provide answers to questions about life on other planets, or reveal the workings of a primordial earth. To many scientists, such lakes are the holy grail of evolutionary biology. Subglacial lake exploration is considered important because:

> "[these lakes have] been untouched and isolated for many thousands of years, without sunlight and under extreme pressure, and we want to find out if there is life in[[them], and if so, how is it living, surviving, adapting and evolving in whatever ecosystem exists down there" (The Engineer, 2009).

Scientific interest into subglacial lake exploration in Antarctica has been high for many years, starting with Lake Vostok in East Antarctica. Recently, a Great Britain-led consortium has started a project to enter a smaller more accessible subglacial lake called Lake Ellsworth in West Antarctica, and a U.S.A. team has plans to drill into an even smaller lake in West Antarctica.

This started an element of competition as to who will be the first to enter an Antarctic lake, to potentially discover previously unseen biological matter and possibly new forms of life. However, it is not known if the drilling technology is at a stage where it is guaranteed that no contaminants will enter the lakes, possibly harming what lies in the water. When operating a drill almost 4km underneath ice, things can go wrong and technology can fail. There have already been two major accidents caused by loss of control of drilling fluid level inside the hole. This must lead us to question the robustness of the technology used and the capabilities of those operating it. Ethical problems are now raised due to the race to be the first to enter a subglacial lake, as environmental standards may be put aside in the race to conduct science.

This paper examines the ethical questions about entering a subglacial lake, 'the last frontier of Antarctic exploration,' to take water samples. First, background material is presented on the projects with a concentration on Lake Vostok which has been the focus of exploration for many years, followed by Lake Ellsworth and the WISSARD project.

Ethical issues raised by this exploration are outlined and further discussed with respect to exploration in general, and by using space exploration and terraforming as analogues to consider the environmental ethics of Antarctic exploration.

BACKGROUND

Subglacial lakes were first detected in 1973 by the use of radar imaging by the Scott Polar Research Institute. Since then more than 145 lakes have been catalogued, primarily through the use of satellite imaging (ERS-1). There is good evidence that some of these lakes are connected into larger systems.

Lake Vostok is the largest subglacial lake in Antarctica with a surface area equivalent to Lake Ontario, of 14,000Km2, containing 5400Km3 of water. It is thought to be part of a network of lakes.

Lake Ellsworth in West Antarctica (Figure 1) is much smaller in comparison to Lake Vostok at only 10km long, but is likely to contain similar biological material to its larger counterpart (M. J. Siegert, 2004). It is thought to be isolated from other lakes.

The Whillans Ice Stream, is much smaller than Ellsworth or Vostok, and is much more dynamic, with portions of the lake completely draining and refilling over the course of a year, and therefore is less isolated than the others. This means that the data taken from it will be very different from the closed systems of the others.

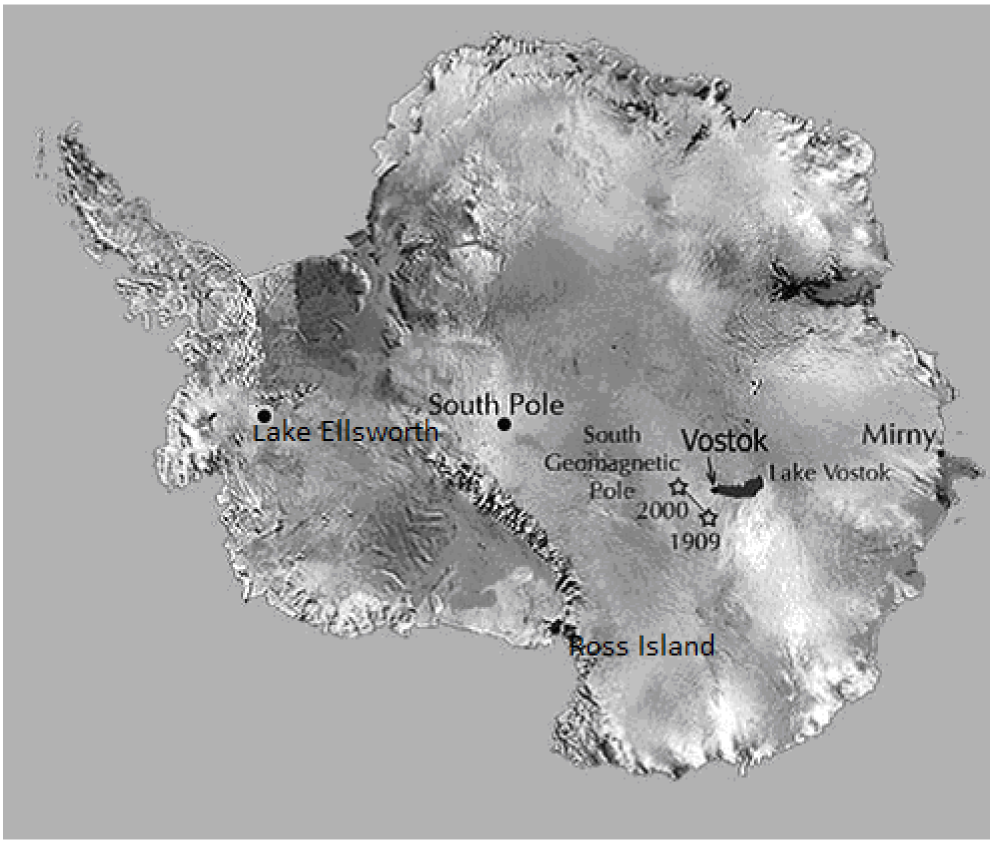


Figure 1. Location of Vostok Station, Vostok Subglacial Lake, Lake Ellsworth and South Geomagnetic pole.

HISTORY OF DRILLING AT LAKE VOSTOK

During the International Geophysical Year of 1957 a Russian research station was established in East Antarctica close to the South Geomagnetic pole (Figure 1), this also happens to be in the most remote area of Antarctica, called Vostok station (N. I. Vasiliev, Talalay, P.G., Bobin, N.E., Chistyakov, V.K., Zubkov, V.M., Krasilev, A.V., 2007). The following austral summer a drilling programme commenced sampling ice cores to a depth of 52m, as they were limited by the drilling technology available at that time (Figure 2). It was not until the late 1960's that further drilling was conducted. Further technological advances in drilling technology were made through collaboration of research and mining institutes, leading to the development of the thermal coring drill capable of much greater depths (Vasiliev, et al, 2007).

Drilling commenced again in 1969, achieving a depth of 250m, and further holes were established in the prevailing years primarily to acquire en-glacial geophysical data from the ice cores (Vasiliev, et al, 2007). At this time it was also discovered that there was a large sub glacial lake directly below Vostok station, confirmed by the airborne radar mapping project and first noted by scientists of the Scott Polar Research Institute in 1973 (Oswald, 1973). The full extent of Lake Vostok was made known by the European satellite ERS-1 In 1996, Figure 4 (Studinger, 2008). Emphasis now changed from studying evidence of climate change in the ice cores, to reaching the subglacial lake to conduct research on the possibility of biological organisms living in the water.

Figure 2. First attempt at thermal drilling at Vostok station (Ignatov, 1962).

Drilling operations over subsequent years saw developments in ice core drilling to overcome problems such as stuck drill heads and off-centre drilling. Significant advances were achieved by the drilling teams with respect to drilling technology of deep ice. This knowledge was shared with other interested parties under the Antarctic Treaty System's principle of sharing scientific knowledge (Antarctic Treaty System, 1991). Five bore-holes have been drilled in the ice (Figure 3) with various offset holes drilled as required when the holes became unusable (Vasiliev, et al, 2007).

The Russian's conducted an environmental evaluation which was approved by the Ministry of Nature Resources of the Russian Federation (Order No. 257, 26 March 2001). In 2003 the project was also presented to the 26th Antarctic Treaty Consultative Meeting in Madrid (Vasiliev, et al, 2007).

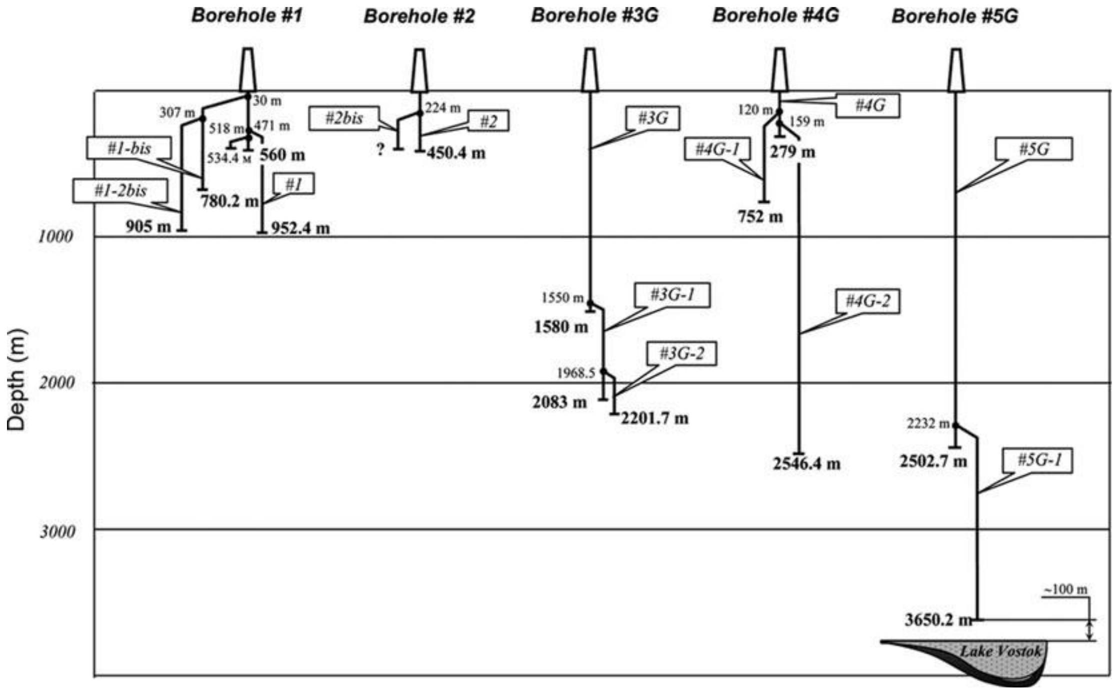


Figure 3. Schematic of deep holes at Vostok station (Vasiliev, et al, 2007).

By the end of the drilling season of 1998, the bore-hole depth was 3623m, approximately 130m away from the lake water (Kudryashov, 2002). Drilling ceased for the next 8 years, during which time bore-hole geophysical measurements were performed before drilling commenced again in the 2005-06 austral summer. Ice fragments encountered at such depth slowed drilling, and required many modifications to drill cutters during the season. By the end of the season a total depth of 3650m had been reached (Vasiliev, et al, 2007).

By the end of the 2010-11 season the hole is within 30m of the lake surface, drilling stopped due to winter approaching and the hole was filled with kerosene to prevent the bore-hole freezing over. The use of kerosene has alerted some environmentalists who suggest that this will find its way into the lake water with possible negative consequences (Boyle, 2011). Bore-hole 5G-1 (‘G’ for deep in Russian) recovered evidence of microbial life in the frozen lake ice, but whether life could be sustained in the actual lake water will not be known until water samples are taken (D'Elia, 2008).

Entering the lake water is controversial as the drilling fluids used to keep the hole unfrozen for the passage of the drill may introduce contaminants, pollutants or alien material into the isolated lake water. Life that may be present in the lake water could be harmed, modified or it is possible extinction could occur unless all precautions with respect to sterilisation of drilling techniques are observed (D'Elia, 2008; Studinger, 2008).

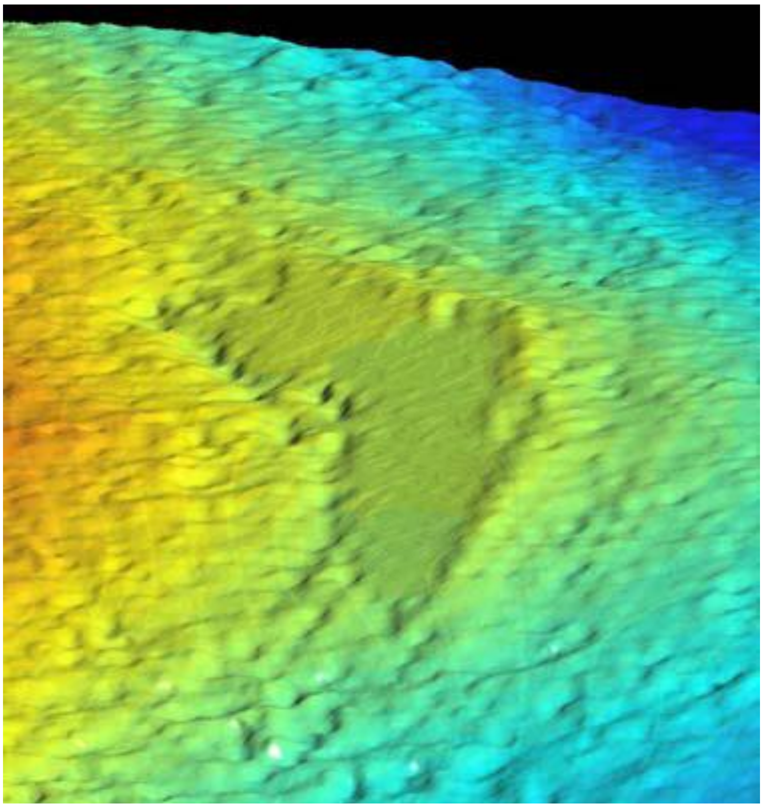


Figure 4. Satellite view of Lake Vostok (Studinger, 2008).

DRILLING TECHNOLOGIES USED TO PENETRATE LAKE VOSTOK

The technology behind drilling programmes such as that at Lake Vostok are technologically advanced and scientifically founded. Currently, the proposed method for sampling the lake 'in theory' rules out any possibility of contaminating the lake with drilling fluid or other materials. However, the programme has had failures in the past and twice has lost drills down the 5G bore-holes due to under-pressurization of the drill hole caused by insufficient drilling fluids in the hole.

DRILLING OF THE CURRENT HOLE

Two types of drill rig have been used to drill the bore-hole to the current depth of 3720.5m as of March 2011 (Vasiliev, 2011). For the most part these drills have been very reliable but there have been a number of issues.

The first 2755m of the hole was drilled using electro-thermal drill rigs namely a TELGA and TPZS. These wire-line electro-thermal (ET) drills are connected to the surface by a cable which lowers and powers the drill. The drill bit is electrically heated and this carves out the ice core. These drills require antifreeze to be added to the water generated in the drilling (C. Bentley, Koci, B, 2006).

From 2755m to 3720.5m the hole was been drilled using KEMS drills (Vasiliev, 2011). These are wire-line electromechanical drills (Figure 5). KEMS drills are also attached to the surface by cables but the barrel contains cutters at the bottom end, and uses a rotary action to cut ice-core. An anti-torque device clings onto the edges of the hole and provides resistance so that the barrel can rotate and cut the ice-core. This type of drill requires the use of Freon/Kerosene as a drilling fluid to prevent hole closure (C. Bentley, Koci, B, 2006).

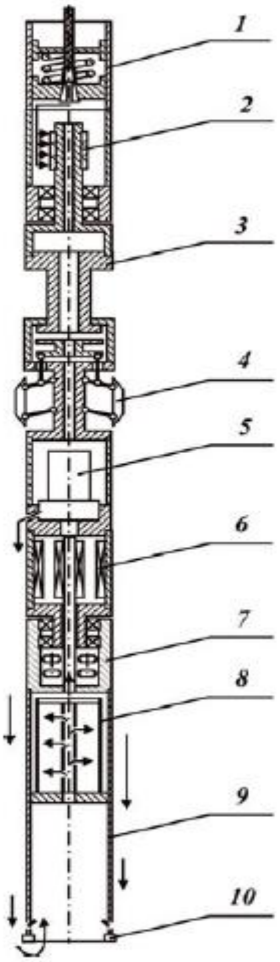


Figure 5: KEMS-112 Electromechanical Drill. 1: Cable termination 2: Electric chamber 3:Hammer block 4: Anti-torque system 5: Pump 6: Electric drive motor 7: Reducer 8: Chip chamber 9:Core barrel 10: Drill head (Vasiliev, et al, 2007).

DRILLING FLUIDS

There is concern surrounding the contamination of the lake by drilling fluids and how this could impact the subglacial lake's environment. The current proposal for sampling the lake involves two drilling fluids, discussed in more detail below.

Drilling fluids are needed for ice drilling at depths greater than 500m. As the hole becomes deeper, enormous pressures are exerted on the bore-hole by the overlying ice. This in effect narrows the diameter of the hole and makes it impossible to retrieve the drill back to the surface. To counter this, deep ice holes are filled with drilling fluid which has a density equal to the density of ice. This fluid must also be non-freezing so that it won’t freeze and trap the drill. The fluid used by the Russians at Vostok station for deep drilling is a Freon/Kerosene mixture, which is also used by the Russians for deep ice drilling in the Arctic and by European countries for the drilling of deep ice holes in Greenland and in Antarctica (Pomelov, 2010). It is considered by Pomelov (2010) that Lake Vostok will not be contaminated by this drilling fluid for a number of reasons: the water in the lake is under intense pressure from the overlying ice-sheet, and once the lake is penetrated the water will move up the bore-hole from the lake. He argues that by decreasing the amount of drilling fluid in the hole it can be ensured that the water pressure in the lake will be higher than the pressure of the drilling fluid inside the hole. Thus the lake water will move up the hole on contact and the drilling fluid will not enter the lake. The Freon/Kerosene mixture is hydrophobic and is lighter than water so it should be impossible for the drilling fluid to leave the bore-hole and enter the lake (Pomelov, 2010).

Silicon oil is the second fluid proposed for use in subglacial lake exploration. This fluid is inert and hydrophobic is planned to be used as a buffer layer at the bottom of the 5G-2 bore-hole before it reaches the lake surface.

ISSUES AND PROBLEMS ENCOUNTERED ALONG THE WAY

In December 1991 the drill got stuck in bore-hole 5G at a depth of 2259m, while the bottom of hole depth was 2502m. The drill became stuck due to a lack of drilling fluid inside the hole, resulting in the hole closing up under pressure from the surrounding ice. It was impossible to retrieve the drill and so the drill was abandoned down the hole. A method called ‘down the hole drilling’ was began at 2243m. This method resulted in a branch hole being established, and the bore-hole was re-named 5G-1 (C. Bentley, Koci, B, 2006).

In January 2007 the drill broke away from the power cable but was retrieved. The next Austral summer season beginning October 2007 the drill was again lost at the bottom of the hole, this time at a depth of 3666m. This accident was also caused by a loss of control of the level of drilling fluid within the hole. The hole once again contained too little drilling fluid. Efforts to retrieve the drill included the use of 450L of diluted antifreeze being poured down the hole. The Russians tried until January 2009 to retrieve the drill from the hole but were unsuccessful (Pomelov, 2010). This resulted in a thirteen metre drill being left in the lower part of the drill hole. The ruined segment of the bore-hole was bypassed by deviating the hole by 1.5m horizontally. This deviation was started at a depth of 3590m and the continuing bore-hole was again re-named 5G-2 (Pomelov, 2010).

These examples demonstrate that the technology and drilling methods used for subglacial drilling are not infallible. A lot has been learned about the drilling of deep ice holes and technology is always improving. As it stands in 2012, there is a slight possibility that something can go wrong down the hole. The loss of two drills so far down the bore-hole which has been branched and renamed twice is flags concerns about reliability of future drilling operations. Both of these major accidents occurred because of a lack of drilling fluids down the hole. The control of drilling fluid in the hole will be crucial in the penetration of Lake Vostok to ensure that the pressure inside the hole is less than the water pressure in the lake so that the drilling fluid will not leak into the lake surface.

Proposed method of sampling Lake Vostok

The proposal for the sampling of Lake Vostok appears to safeguard against the contamination of the lake by the drills or drilling fluids used to penetrate it.

The proposed method for future drilling involves a thermal and electromechanical drill. The lake surface is at 3760m (+/-15m) and the hole depth was at 3650m by February 2010. Which left approximately 110m left to drill to reach the surface of the lake (Vasiliev, 2011). In the 2010/2011 austral season the KEMS-135 electromechanical drill was used to drill to a depth of 3720.5m. This drilling used a Freon/Kerosene mixture as drilling fluid. The current drilling season of 2011/2012, the Russians plan to start using a hydrophobic and inert drilling fluid such as a silicon fluid (e.g. polydimethylsiloxane), this will be used to replace the Freon/Kerosene mixture within the bottom 100m of the hole (Vasiliev, 2011). This fluid will be heavier than drilling fluid but lighter than water so will buffer the bottom of the hole and the eventual lake water from the drilling fluid (Vladimir, 2010).

From the current bore-hole depth of 3720.5m, a coreless thermal drill TBPO-132 (Figure 6) will now be used to drill the remaining 40m of the hole and to penetrate the lake. This drill is a total of 7m long, including a 5m long main drill with a 132mm diameter drill bit. There is also a 2m long pilot micro-drill which drills a 50mm diameter pilot hole in front of the advancing main hole (Vasiliev, 2011). This thermal drill is washed over by the melt-water produced during drilling and this will create a second buffer layer between the bottom of the hole and the drilling fluid (Vladimir, 2010). The micro-drill contains a sensor at the end which will detect when the lake surface is reached. This will automatically stop the drilling once the lake surface is reached and turn on a packer which completely blocks the hole (Vladimir, 2010). It is most likely that the pressure in the lake is going to be higher than the pressure in the hole so it is expected that the water from the lake will move up the bore-hole. The height the lake water reaches in the bore-hole will depend on the pressurization of the hole controlled by the amount of drilling fluid inside the hole (Pomelov, 2010). There is a chance that the pressure inside the hole is greater than the pressure in the lake but because the drill acts as a nipple in the hole there is no chance of fluid transfer from the hole into the lake as the fluid at the bottom of the hole at this stage is likely to be melt water (Vladimir, 2010).

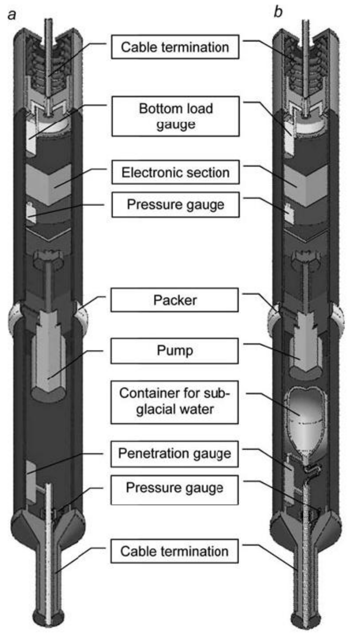
Figure 6: Thermal drill

TBPO-132

(a) without sampler

(b) with sampler

(Vasiliev, et al, 2007).



The Russian plan is to allow lake water to fill the bottom 30-40m of the hole, and once this water has frozen the new ice will be sampled using the KEMS-135 electromechanical drill. It will be sampled at a depth which is 15-20m above the lake surface (Vasiliev, 2011) .

The TBPO-132 has been specifically designed for this job and the method for sampling the lake water seems to be foolproof. It will create two buffer layers between the drilling fluids and the lake water, and the thermal drill will act as a plug at the bottom of the hole (Figure 7). The protection of the environment seems to have been the most important factor in the design of the drill and in the proposed method for sampling Lake Vostok.

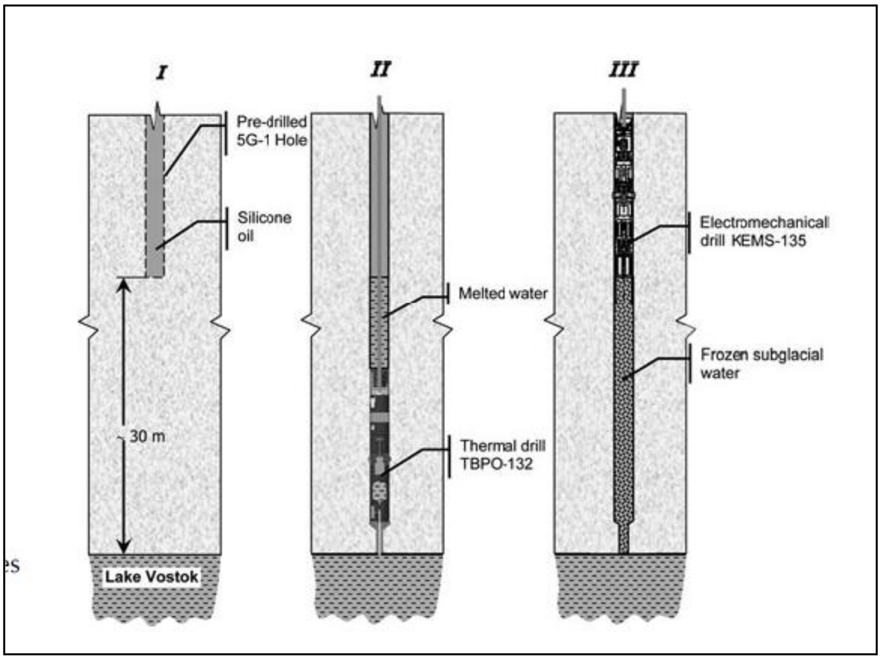


Figure 7: Schematic showing the proposed method for sampling the water of Lake Vostok (Vasiliev, et al, 2007).

POTENTIAL ENVIRONMENTAL RISKS THIS METHOD

The two main technological risks identified with the penetration of Lake Vostok involve the failure of the drill and the contamination of the lake by the drilling fluids. If the drill becomes stuck and it cannot be retrieved (as has happened twice in the past,) then the drill is left in the bore-hole and the hole is deflected around the failed section. If the Kerosene/Freon drilling fluid mixture somehow enters the lake then the kerosene will bring with it 10,000-100,000 cells into the lake for every millilitre of drilling fluid. These cells are of at least two species *Spingomonas aurantiaca* and *Haloanella gallinarum*.

Although Russian scientists describe fluid leakage as less than minor and transitory impact because of doubts the bacteria would be active in such lake conditions, this view may not be shared by all. As Lake Vostok's eco-system has been untouched since its creation, the act of sending a probe into its hidden depths could alter the underwater ecosystem, permanently damaging it for future generations. The techniques used by the drilling programmes rely on crude and un-sterilized equipment, which could result in the introduction of foreign bacteria and viruses into the unknown microbial world.

In case of contamination of the lake by the drilling fluid mixture it is predicted that the kerosene will oxidise completely for a short time and that the bacteria in the drilling fluid will be killed by the environmental conditions inside the lake (Pomelov, 2010).

PLANNED DRILLING AT LAKE ELLSWORTH

The sampling of Lake Ellsworth has been put forth as a substitute for Lake Vostok and there is competition from the British lead Lake Ellsworth team who believe that this lake should be concentrated on instead of Lake Vostok. Ellsworth is a much smaller lake than Lake Vostok at only 10 km long and 2-4km wide. Lake Ellsworth lies about 3400m underneath the West Antarctic Ice Sheet near to the Ellsworth Mountains in West Antarctica (M Siegert et al., 2007).

The proposed method of penetrating and sampling Lake Ellsworth is much different from that proposed for Lake Vostok. The Ellsworth team plans to drill a hole to the lake surface using a hot water drill (M Siegert et al., 2004). This type of drill users pressurized hot water from a nozzle to melt the hole it is an extremely fast method but does not recover any core (C. Bentley & Koci, 2006). Hot water drills do not need drilling fluid or anti-freeze for drilling but the hole will not stay open for a long time and it is believed that this hole will only stay open for 24-36 hours. Once the hole is drilled the team will lower a probe through the borehole into the lake and to the lake floor. The probe will measure among other things the lakes pressure, temperature, chemistry and bio-molecules and is geared to detect any life forms. The probe may also take some water samples for future analysis from the lake. It is also planned to lower a sediment corer on to the lake floor to retrieve a 2m sediment core (M Siegert, et al., 2007).

Environmental arguments put forth in favour of drilling into Lake Ellsworth instead of Lake Vostok include the fact that the base of the West Antarctic Ice Sheet under which Lake Ellsworth is located has been reached and studied previously while the base of the East Antarctic Ice Sheet which overlies Lake Vostok has never been reached by drilling. It is argued that the environmental issues at Ellsworth will be easier to overcome as the base of this ice sheet has already been drilled and studied. Also geophysical data indicates Lake Ellsworth is separated from other Antarctic Lakes (M Siegert, et al., 2004) while this data is inconclusive at Lake Vostok which is a much bigger system.

The Ellsworth team hopes to start drilling in the 2012/2013 summer season and their hole will be completed in an estimated fifty hours once drilling is started (M Siegert, et al., 2007). As the Russian team is was only about 40 meters from Lake Vostok's surface as of the start of the 2011/2012 season it has literally become a race to be the first to sample an Antarctic subglacial lake.

It appears that there is some justification in arguing that it would be more environmentally ethical to drill into and sample Lake Ellsworth as a substitute for Lake Vostok; due to it perhaps being a simpler operation and without the risk of drill fluid contamination. Although the method of sampling Ellsworth will not include any drilling fluid it does appear to be more intrusive with a probe actually entering the subglacial lake and with the proposed action of obtaining a core from the lake sediments. What is certain is that the element of competition now in effect will not be beneficial to the environment as the two teams will strive to be the first to sample a subglacial lake and in their haste environmental standards may be compromised.

THE WISSARD PROJECT

The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) Project is a U.S. led endeavour to study the subglacial environment of the Whillans Ice Stream in West Antarctica. This project has three sub-projects: the Lake and Ice Stream Subglacial Access Research Drilling, the Robotic Access to Grounding-zones for Exploration and Science, and the GeomicroBiology of Antarctic Subglacial Environments, each with their own distinct aims. The Whillans Ice Stream, where three hydrologically connected subglacial environments lie within, will be directly sampled over a six year initiative to assess the hydrological continuum. Concern with contamination, which shares many of the same issues as Lake Ellsworth and Lake Vostok, are reduced by the fact that the system is at the end of an active hydrologic catchment, meaning that any contamination would be contained. Additionally, to assess contamination the U.S. program continues to undergo protocol assessments to clean the surfaces of cables/hoses and drilling equipment to mitigate/eliminate contamination (Kelly, 2009). This lake, which is much smaller than Ellsworth and Vostok, is much more dynamic, with portions of the lake completely draining and refilling over the course of a year, and therefore is less isolated than the others. This means that the data taken from it will be very different form the closed systems of the others.

ETHICAL ISSUES RAISED BY THE EXPLORATION OF SUBGLACIAL LAKES

It is clear that the exploration of these lakes could provide answers to many important scientific questions. Of most interest is the possibility that they contain life forms that have been isolated from the rest of life on earth for millions of years.. However, there are many who oppose the exploration and would much rather see the subglacial lake remain undisturbed, as Lake Vostok has been for 30 million years. For example the Antarctic and Southern Ocean Coalition (ASOC) is very much against drilling into Lake Vostok as they think it may be connected to other subglacial lakes and think it is best to join with other countries to penetrate a smaller, more isolated lake that will reveal the same data (ASOC, 2008). The ethical implications of the scientific exploration of the lakes unearth the underlying question: how can we pursue the continued exploration of Antarctica and its oceans while still applying serious ethical consideration to such projects?

Pros and Cons

There are a variety of reasons to push forward with exploration into these lakes, as noted in a workshop (Bell, 1998) devoted to developing strategies for research. It is thought, for example, that:

- Lake Vostok may contain an active tectonic rift, further increasing knowledge of the East Antarctic geologic terrains
- All of the lakes hold a sedimentary record of earth's climate, with important information about the beginnings of Antarctic glaciation
- All are un-described extreme earth habitats with unique geochemical characteristics
- All may contain novel, previously un-described, relic or fossil micro organisms with unique adaptive strategies for life – and that these may be common to all lakes or unique for each lake
- The efforts may be a useful earth-based analogue and technology "test-bed" to guide the design of unmanned, planetary missions to recently discovered ice-covered seas on the Jovian moon, Europa (Bell, 1998)

Against these possible benefits the researchers must weigh certain legal and ethical considerations. Environmental ethics, as Taylor states, is primarily the moral relationship between humans and the natural world (Taylor, 2011). These relations are sometimes, but not always, articulated in guidelines and enforced through law. However, there are situations where environmental ethics clash with human interests. As human civilization has evolved, our expansion has required the consumption of natural resources. While in the past our numbers have been capped, modern medicine and industrial advances have extended our ability to grow and spread to almost all the inhabitable areas of the globe. No doubt, there have been repercussions of this advance, many of them at the expense of the ecosystem. As Rolston notes, an anthropocentric environmental ethic is simultaneously possible, required, and troubling on the other six continents, because "people are undeniably helped or hurt by the condition of their environment" (2002). However, unlike anywhere else, Antarctic research and exploration should be governed by a global, as opposed to a "national" ethics system perhaps within the Antarctic Treaty. In order to do this, a trans-cultural method of preserving science on the continent is needed.

The question is then raised, do we have a responsibility to the natural world that is separate from our responsibility to ourselves, and what rights should we give human interests in the region? The Russian drilling programme, which was halted before it reached the surface of the lake, has yet to submit a final (Comprehensive Environmental Evaluation) CEE. This submission would fulfil obligations under Articles 3.5 and 3.6 of the Madrid Protocol (Antarctic Treaty System, 1991). However, Russia has no real need to submit this CEE, as no law effectively prevents its researchers from continuing drilling. Currently policy states that science has priority in the Antarctic legal system, therefore the drilling project to sample water in the lake and uncovering answers as to what life forms lie beneath has priority under the current treaty system.

The ethical issues posed by the exploration of these lakes are applicable to any scientific endeavour in Antarctica, and globally. As demonstrated by experiments in quantum mechanics, the mere act of observation affects experimental findings (Weizmann Institute of Science, 1998). This is an altogether too real possibility for these projects.. This then raises the question: is there an acceptable level of contamination, and if so, where does it lie on a spectrum? In many respects, this lake is not "our world". A true naturalist would say it belongs to those blissfully trapped "alien" microbes, and some say might say who are we to play god?

The easiest way to prevent the contamination of these lakes is to simply stop all drilling projects and use wholly non-invasive systems for study, such as mapping projects. However, to many, this view is akin to abstinence and poses the question: If nobody can properly research the region, what is the real value of these unique Antarctic lakes? Does the effort to preserve Antarctic subglacial lakes run contrary to our human nature to explore and discover?

The final point above relates to the analogue of these lakes to the bodies of Europa and Callisto. The techniques used in spatial exploration of sub-surface water areas are of particular interest to Antarctic scientists. These drilling projects, much like the planetary sites, require vehicles to manoeuvre through vast distances of ice, 4 to 10 km vertically, and require communication of data through layers of fluid and frozen water (Bell, 1998). Scientists on earth and in outer space must test the possibility of a negative outcome, which is no simple task. The robotic difficulties of both areas present technological challenges to engineers, and Antarctica is potentially a perfect testing ground for exactly that.

ETHICAL ISSUES

THE SEARCH FOR LIFE

Since the dawn of civilization the human species has engaged in the quest to uncover new types of life, normally to exploit them if possible. The right to engage in this activity has never been widely questioned. In fact the theology of major religions includes statements similar to Genesis 1:26 – that man should "rule over the fish of the sea and the birds of the air, over the livestock, over all the earth, and over all the creatures that move along the ground." Humanity's dominion has resulted in the complete extinction of many species of plants and animals, both from intentional actions and from unintentional contamination.

Only recently has this right to dominion over all living things been critically examined, with the assignment of rights to non-human life embodied in the concepts of Gaia and the philosophy of "Deep Ecology". Even as these philosophies reduce man from the centre of creation to part of the wider ecosystem, they place no restrictions on mankind's efforts to extend knowledge, as long as it is done with the spirit and understanding of the "wholeness" of all life and environments (Arne, 1973).

It appears that most humans, and virtually all scientists involved in this research, take it as a given that we have a human right to seek life in all environments.

INTRINSIC VALUE OF THE WILDERNESS

The notion that wilderness environments have intrinsic value, and thus rights to protection from human intervention based on that value, is well established. Many people believe that there is justification in the preservation of some environments completely outside of human intervention to preserve remaining wilderness.

On the flip side of arguments that promote the value of wilderness is the notion that no place or life is more special than another. This principle states that any living organisms (most likely in the form of microbes) found on Mars or in a subglacial lake are just another part of the wider web of life, and therefore deserving of no special protection. They are in competition with other life forms in the standard Darwinian evolutionary model (Darwin, 1859), and thus any human impact on them is no different than human impact on the microbes of the soils or oceans of earth.

AGENT-CENTERED RESTRICTIONS

In recent scientific argument, the concept of agent-centred ethics has emerged. This holds that some actions should be restricted due to the responsibilities of the explorers and researchers themselves, rather than the rights or values of the environments or organisms being explored. The concept is that "priority should be given to the constraints humans ought to impose on themselves, even (and especially) if they do not know the nature of a given object of exploration (say, a primeval ecosystem) and the consequences their actions may have for this object" (McArthur, 2004).

These principles require that humans refrain from exploration when the results of the exploration to the explored are either too dangerous or damaging, or unknown.

So far these principles have not prevented exploration in Antarctica, but they have perhaps slowed it down and made the researchers more cautious. We also note that they are not unprecedented. The tomb of China's great emperor Qin is located under a large mound very close to the famous terracotta warriors that guard it. According to ancient texts it contains a vast treasure that has not so far been looted. However, the Chinese government has repeatedly denied requests to excavate the tomb, saying that the required technology and knowledge is not yet available to do the job properly (Wiki, 2012).

On the flip side of the principle of agent-centred restrictions is the concept that human destiny and human nature requires us to use our abilities to their maximum potential, and thus to 'boldly go where no man has gone before'. Any failure to do so could be seen as an abrogation of our responsibility to ourselves, our ancestors, and our descendants (McArthur, 2004).

OVERLAP WITH SPACE EXPLORATION

Antarctica has served as the test bed for numerous space exploration projects. The similarity of the continent, especially the ice free areas, to the environments found in extraterrestrial worlds makes it a natural choice for this work. Lunar and Martian rovers have been tested there, and studies have been conducted on the ability of humans to adapt to extreme environments.

Exploration efforts in Antarctica and in particular the current projects to drill into the subglacial lakes, raise many ethical issues. Perhaps it is time to turn the tables and see what can be learned from an examination of the ethics of the exploration of space and celestial bodies that is of relevance to Antarctic exploration.

There are many similarities in the ethical aspects of these two fields of exploration. Both seek to make initial contact with pristine environments; both seek to discover whether any life exists in these environments; both try to ensure that the pristine environment is not contaminated in the process; and both expose issues related to the rights and values of the environments and humans when making these efforts.

The ethical issues related to terraforming also have relevance to Antarctic exploration and potential exploitation. Terraforming is the proposed alteration of a celestial body to make it suitable for human habitation. The similarities relate to the values placed on non-living objects and the intrinsic values of preserving parts of the world or the solar system from human interference (Marshall, 1993).

GOVERNANCE

The framework for the protection of the Antarctic environment is the Antarctic Treaty System. This System makes an effort to codify the rights and responsibilities of the nations and individuals engaged in activities in the Antarctic – including science and exploration. Unfortunately, it is vague and non-proscriptive when it comes to the fundamental environmental and ethical issues.

In a very similar fashion, the framework for the protection of outer space is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (informally known as the Outer Space Treaty). The Treaty entered into force on October 10, 1967 (vs. June 23, 1961 for the Antarctic Treaty). As of today, some 126 nations have ratified the Outer Space treaty or are in the process of doing so. The articles of this treaty restrict activity in ways similar to the Antarctic Treaty – no nuclear weapons, weapons testing or military maneuvers; restricting use to “peaceful purposes”; requiring that exploration shall be done to benefit all countries; and reserving space as the “common heritage of mankind”. Like the Antarctic Treaty it is short on specifics and enforcement.

The formal legal frameworks for outer space and Antarctica are similar in their goals and structures, and also similar in that they provide broad guidelines but little specific regulation or enforcement. They are of some value when it comes to issues of national sovereignty, and for issues related to military activities, but of little value when trying to make decisions on the rights of explorers and scientists. So, it is useful to look outside of these sources to search for consensus or uncover the various points of view.

ETHICS

The search for life now is extended to outer space and to subglacial lakes. As in previous exploration, the track record in outer space is not good. While no direct contamination or extinction can be shown, the recent Galileo probe to Jupiter was not sterilized before it was sent to enter the Jovian atmosphere (Garcia, 1989). Thus it seems that the value placed by researchers and explorers of the potential new life does not extend to allowing it to remain isolated – no matter where it is.

Both outer space and subglacial lakes are virgin wildernesses, and thus potential candidates for protection based on their intrinsic value. This has not stopped the sending of space probes to many celestial bodies, and humans to the moon. Any argument for the intrinsic wilderness value of the moon or Mars was completely lost in the public clamour for the “space race” and the public interest of the Martian rovers.

This lack of public response to the intrusion into the wilderness of space indicates that while there is some acceptance of wilderness values in the wider community, there is no acceptance the any virgin wilderness should be reserved from exploration. Rather, once explored, some portion of that wilderness may be given partial protection from human activity, as with nature reserves, national parks, of sites of special protection and management in Antarctica. It is thus reasonable to expect to see Mons Olympus Park on Mars and Lake Vostok or other subglacial lakes being Antarctic Specially Managed Areas (ASMAs).

The responsibilities felt by the explorers and researchers to "do the right thing" do seem to have had some effect in tempering their behaviour. For both space exploration and subglacial lake penetration extreme measures have been taken to prevent contamination.

PARALLELS

The ability of any legal or ethical framework to be established, gain consensus, and guide activities, is difficult for the exploration of outer space and Antarctica for the same underlying reasons. The lack of any overarching government or native inhabitants makes the establishment of a binding legal framework problematic or impossible. In the absence of this, each individual or nation is free to decide for themselves which actions are morally correct, and which are not. Some of these states, including the Scientific Committee on Antarctic Research (SCAR, 2011) have made efforts to establish rules and consider the ethics of their actions, but these are not well developed or mature, and the pace of exploration is not likely to be slowed while they catch up.

Given the historic competition among people and nation states, the moral and ethical high ground of complete protection of the environment will likely remain unoccupied. The quest for wealth and knowledge will continue to see the exploration of both domains. The principle of 'common heritage of mankind' is likely to promote moderation in this exploration compared to what would happen inside of a legal framework in any state. The environmental values applied will drive the protection of alien worlds or subglacial lakes from contamination to a higher standard than would otherwise be the case.

The devolution of the moral responsibility to the individual or nation when making decisions on whether, when and how to proceed with exploration does not mean that no ethical evaluations are made. Only that they are likely to be a sidelight to the major work of the project, and that as the race to Mars or the race to a subglacial lake heats up, they are less likely to guide the actions of the participants.

ANTARCTIC TREATY SYSTEM GUIDELINES

While the ATS has no formal power of enforcement, the Scientific Committee on Antarctic Research (SCAR) has a set of guidelines for the code of conduct for the exploration and research of subglacial aquatic environments in draft form. These guidelines were proposed at the most recent ATCM meeting in July 2011, and include as general principles

> "Responsible stewardship during the exploration of subglacial aquatic environments should proceed in a manner that is consistent with the Protocol on Environmental Protection to the Antarctic Treaty, that minimizes their possible damage and contamination, and that protects their value for future generations, not only in terms of their scientific value but also in terms of conserving and protecting these pristine environments" (SCAR, 2011).

And

> "Exploration protocols should also assume that the subglacial aquatic environments contain living organisms, and precautions should be adopted to prevent any permanent alteration of the biology (including introduction of alien species) or habitat properties of these environments" (SCAR, 2011).

This approach by SCAR is consistent with the design and development of the Antarctic Treaty. Under the treaty scientific values have the highest priority. The rights of the environment or other intrinsic values are secondary. Having said that, the ATS does place high value on environmental protection, as codified in the Madrid Protocol and enforced through the Committee for Environmental Protection.

CONCLUSIONS

The technology used by the various drilling programs is state of the art. The Russian bore-hole at Lake Vostok is at the cutting edge of deep ice drilling. Very careful consideration has been taken to ensure that the method which will be used for the sampling of the lake surface will not contaminate the lake itself. A specially designed drill will be used for the final penetration of the ice above Lake Vostok and the use of an inert silicon drilling fluid will be used as a buffer layer to further ensure that the lake is not contaminated by any harmful material. However, the machinery is very new and the operation of a drill at such extreme depths and conditions creates some risk. There have been several problems in the past with the drilling of this hole. Two accidents caused by loss of control of the drilling fluid level in the hole have resulted in two drills being left down the hole; each time the hole was branched off to avoid the failed section.

Likewise at Lake Ellsworth and in the WISSARD project the most advanced available technology is being employed. And likewise even the best available technology does not guarantee that there will be no contamination. Mistakes are always possible.

One implication is that although the technology appears to be the best available there is always some inherent risk with machines, experimental methods and extreme conditions. The risk of failure is considered very low indeed but not impossible. Failure could result in the contamination of a unique and un-touched environment on the Earth and must be weighed against the need for scientific sampling and the implications such sampling holds. The surest and most environmentally ethical way to ensure that the lake is not contaminated is to delay the drilling projects until further research fosters better technology and more reliable drilling methods. For ethical reasons we must weigh the importance of human exploration and the gaining of knowledge against the possibility that such exploration will contaminate one of the last remaining pristine environments on Earth.

The SCAR guidelines set a good precedent and should help to insure some commonality for making judgments. But, ultimately it is left to the individual science projects and associated countries to answer their own ethical questions. It could be argued that Russia should have priority to drill into an Antarctic subglacial lake due to the development in drilling technology they have achieved over the many years of subglacial drilling. Also, as the Russians have a long established drilling base at Vostok, why is there a need to double up drilling operations in Antarctica to obtain the same results? On the other side, it could be argued that Lake Ellsworth be penetrated first, as it is smaller and therefore not as significant if contamination happens.

Whatever your opinion on the ethical questions, it is acknowledged that the race has started; drilling is underway in Antarctica and will not likely stop until all three lakes are sampled.

Will any micro-organism found survive the experience? Time will tell.

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